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ABSTRACT

This study provides spatially disaggregated estimates of greenhouse gas emissions from the major anthropogenic sources for 145 countries. The data compilation is comprehensive in approach, including emissions from CO, CH_4, N_2O and ten halocarbons, in addition to CO_2. The sources include emissions from fossil fuel production and use, cement production, halocarbons, landfills, land use changes, biomass burning, rice and livestock production and fertilizer consumption. The approach used to derive these estimates corresponds closely with the simple methodologies proposed by the Greenhouse Gas Emissions Task Force of the Intergovernmental Panel on Climate Change. The inventory includes a new estimate of greenhouse gas emissions from fossil fuel combustion based principally on data from the International Energy Agency. The research methodologies for estimating emissions from all sources is briefly described and compared with other recent studies in the literature.

INTRODUCTION

This study presents a comprehensive inventory of greenhouse gas emissions for the major anthropogenic sources of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O) and halocarbons for 142 countries.[1] The study provides the first country-specific assessment of CO, CH_4, and N_2O emissions from both land use changes and energy sources. For the remaining sources and gases, the inventory extends and refines previously published research. With the exception of landfill emissions, the approach used draws only on international databases with country-specific sources; it is compatible with the simple methodologies outlined in the OECD's report, Estimation of Greenhouse Gas Emissions and Sinks (OECD 1991) prepared for the Intergovernmental Panel on Climate Change (IPCC).

National inventories of anthropogenic greenhouse gas emissions have a number of uses. They provide a basis for setting country-specific priorities for controlling emissions of gases from different sources and sectors. Baseline emissions estimates also establish a reference for monitoring a nation's progress towards achieving greenhouse gas emissions targets. In addition, more accurate national inventories may contribute to a more complete picture of total sources and sinks and to reconciliation of emissions data with known GHG concentrations in the atmosphere.

Any attempt today to develop comprehensive inventories of greenhouse gas emissions at the country level necessarily involves heroic assumptions. Apart from industrial CO_2 and halocarbon emissions, estimates from most greenhouse gas sources involve large uncertainties. Nevertheless, such efforts provide indicative estimates of emissions at the country level and initial results to which subsequent studies refining components of the inventory can be compared.

The international research community is in the early stages of developing inventories at the country level. The Intergovernmental Panel on Climate Change has outlined a three-year program for completing national greenhouse gas emissions inventories. Their efforts are not geared towards a baseline for negotiations as much as an international process for harmonizing accounting methods, stimulating further research and analysis, and identifying the areas of uncertainty in the data and methodology. Several inventories of national greenhouse gas emissions have already been completed for selected greenhouse gases. The World Resources Institute has published "The Greenhouse Index," which provides estimates of CO_2, CH_4, and halocarbon emissions and their contribution to atmospheric warming (WRI 1990). The member states of the European Communities have been developing emissions inventories from energy consumption (OECD 1991). Many countries that support the IPCC's emission inventory program are working on detailed accounts of emissions from their own countries; as these studies are completed, they can be compared to the estimates developed here.

[1]The inventory is the basis for an ongoing project to develop alternative scenarios of future emissions by country. The Stockholm Environment Institute has developed a computer-based accounting tool for this purpose called the Greenhouse Gas Scenario System (G2S2).

1 OVERVIEW

Many human activities generate greenhouse gases including energy production and use, manufacturing and agricultural processes, land use changes, and waste disposal. Country-level estimates of anthropogenic emissions of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O) and halocarbons are assembled from separate inventories for each of the "sources" shown in the first column of Table 1.1. For each source, emissions are computed as the product of an "activity level," a measure of the type and scale of the anthropogenic source, and an "emissions factor," the quantity of gas emitted per unit of activity.

Currently available data has permitted consideration of most activity levels at the country level, while many emissions factors are not available at this level. The level of spatial specificity is summarized in Table 1.1. For the fossil fuel accounts, country-specific emission factors were derived and used; for the other sources emissions factors are regional or global. Region-specific emissions factors include methane emissions from livestock, rice paddies, and natural gas transport. In the case of landfills and land use changes, carbon density estimates are regional. For the remaining sources, including fertilizer consumption, wood-fuel consumption, and cement production, emission factors are global. Uncertainty in emissions estimates varies greatly by source as indicated in Table 1.2 and discussed in Sections 2 through 5.

Global annual anthropogenic emissions of greenhouse gases from all sources is found to be as follows: CO_2: 6.43 Gt CO_2-C; CO: 486 Mt CO-C; CH_4: 352 Mt; N_2O: 3.78 Mt; CFCs: 1.37 Mt CFC-11 Equivalents[2]. The Annex to this report gives results by gas, source, and country. The annual global emissions estimated in this study are compared to the IPCC's (Intergovernmental Panel on Climate Change) results in Tables 1.3-1.6.

[2] CO_2 and CO emissions are expressed throughout this report as mass units of carbon while CH_4 and N_2O are expressed by total molecular weight. Halocarbon totals are expressed as equivalent CFC-11 warming potential based on the IPCC's 100 year global warming potential (GWP) figures (IPCC, 1990b).

Table 1.1 Regional specificity of data

Sources	Activity level	Emission factors
Energy		
Fossil fuel consumption	C	C
Wood fuel consumption	C	G,R
Fossil fuel production	C	C,R,G
Oil flaring	C	G
Natural gas trans. & dist.	C	R
Cement	C	G
Land use		
Deforestation	C	R
Afforestation	C	R
Soil disturbances	C	R
Other biomass burning[a]	R	G
Agriculture		
Enteric fermentation	C	R
Animal wastes	C,R	R
Rice cultivation	C	R
Fertilizer consumption	C	G
Landfills	C	C,R,G
CFCs		
CFCs 11, 12, 113, 114, 115, H-1211, H-1301	C,R	R
Other CFCs and HCFCs	C,R	R

Note: C = country-specific; R = regional; G = global.

[a]Other biomass burning includes emissions from grasslands, agricultural residues, shifting cultivation and prescribed burning (e.g. fires set for fire prevention).

Table 1.2 Accuracy of emissions accounts

Sources	CO_2	CO	CH_4	N_2O	CFCs
Energy					
Fossil fuel consumption	H	L	M	M	
Wood fuel consumption		L	L	L	
Fossil fuel production			M		
Oil flaring	M				
Natural gas trans. & dist.			M		
Cement	H				
Land use					
Deforestation	M	L	L	L	
Afforestation	L				
Soil disturbances	L			L	
Other biomass burning		L	L	L	
Agriculture					
Enteric fermentation			M		
Animal wastes			L		
Rice cultivation			L		
Fertilizer consumption				L	
Landfills			M		
Halocarbons					H

Note: High, Medium, and Low accuracies for global emissions: H ≤10%; M ≤50%; L ≤100%. Estimates of accuracy are derived from the IPCC (1990b, 1991). Uncertainties are generally greater at the country level, particularly in developing regions.

Table 1.3 Global carbon dioxide emissions compared (Gt CO_2-C)

Anthropogenic sources	This study	IPCC (1990b)
Energy	5.4	5.2 - 6.2
Cement	0.1	
Deforestation	1.4	0.6 - 2.6
Afforestation	-0.5	
Total	6.4	5.8 - 8.7

Table 1.4 Global carbon monoxide emissions compared (Mt CO-C)

Anthropogenic sources	This study	Khalil and Rasmussen (1990)
Fossil fuel combustion	169	170-428
Fuelwood	43	
Other biomass burning	274	144-600
Total	486	

Table 1.5 Global methane emissions compared (Mt CH_4)

Anthropogenic sources	This study	IPCC (1992)
Energy		
Coal mining	49	
Oil and gas systems	30	
Subtotal	79	70-120
Livestock		
Enteric fermentation	75	65-100
Wastes	28	20-30
Subtotal	103	
Rice cultivation	98	20-150
Landfills	36	20 - 70
Biomass burning	36	20 - 80
Total[a]	352	215-550

[a]Not included is an estimated 22 Mt CH_4 arising from wastewater (Orlich 1990). For comparison approximately 150 Mt CH_4 are emitted from natural sources: CH_4 hydrates 5 Mt; oceanic production and production by termites 30 Mt; natural wetlands about 115 Mt (Crutzen 1991).

Table 1.6 Global nitrous oxide emissions compared (Mt N_2O)

Anthropogenic sources	This study	IPCC (1992)
Energy	1.3	0.5 - 1.4
Biomass burning	1.6	0.3 - 1.6
Soil disturbances[b]	0.1	
Fertilizer consumption	0.8	0.1 - 4.7
Total	3.8	0.9 - 7.7

[a]IPCC 1991
[b]Includes estimates from Latin America only.

An estimated 85 percent of net CO_2 release comes from energy and 13 percent from land use changes as shown in Figure 1.1. Cement production makes up about 2 percent of CO_2 emissions. The anthropogenic CO_2 emissions are estimated at about 6.4 Gt CO_2, which is within the range identified by the IPCC. An estimate of about 0.5 Gt CO_2 sequestered annually through afforestation and forest products reduces the total net release from biota to 0.9 Gt CO_2.

About 169 Mt CO, or 35 percent of the total is estimated to be released from fossil fuel combustion with the remainder due to fuelwood and other biomass burning (see Figure 1.2). About three-quarters of the biotic emissions, which are estimated at 274 Mt CO, may originate from shifting agriculture, savanna fires, and agricultural wastes according to a recent study (Crutzen and Andreae 1990). This total, 486 Mt CO, is within the range cited by the IPCC (Khalil and Rasmussen, 1990).

Breakdowns of global annual methane emissions by source are shown in Figure 1.3 and Table 1.5. Fossil fuel sources contribute about 79 Mt CH_4, which approaches the range of 80 - 120 Mt CH_4 from fossil fuel sources estimated through measurements of atmospheric concentrations of ^{14}C-free CH_4 (Crutzen 1991). Methane from bacterial anthropogenic sources

Figure 1.1 Carbon dioxide emissions by source

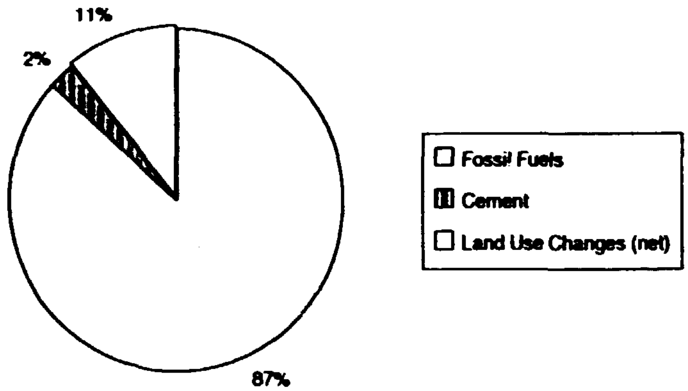
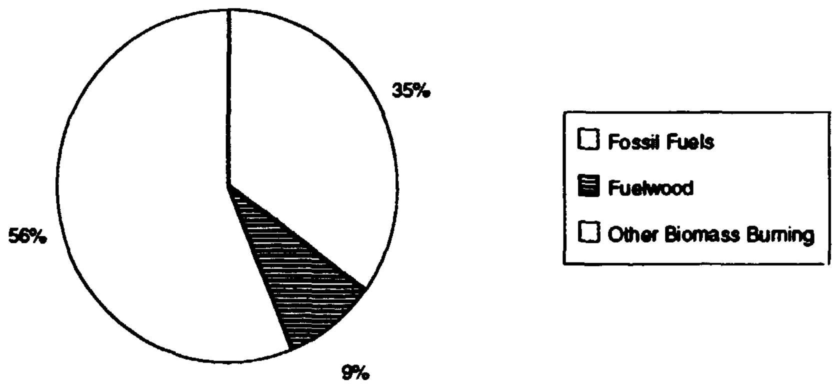


Figure 1.2 Carbon monoxide emissions by source



-- rice cultivation, landfills, enteric fermentation and animal wastes -- is estimated to be about 237 Mt CH_4. If emissions from wetlands are considered as well, this estimate is consistent with global CH_4 budgets that place bacterial emissions at between 70 and 90 percent of total CH_4 emissions (Cicerone and Oremland 1988).

Global annual nitrous oxide release from the anthropogenic sources included here is about 3.8 Mt N_2O. The relative source contribution appears in Figure 1.4 and Table 1.6. About 1.3 Mt N_2O is estimated to be released from energy combustion and 0.2 Mt from biomass burning to clear land. Adding in Crutzen and Andreae's (1990) mid-range estimate of 1.4 Mt N_2O from burning of grassland and agricultural waste and from shifting agriculture, brings the total to about 2.9 Mt N_2O from fuel and biomass combustion. These estimates are on the high end of the IPCC's revised N_2O range of 0.8 - 3.0 N_2O from energy combustion and biomass burning (1992). About 0.1 Mt N_2O is estimated to be released from pasture converted from forests in Latin America, and about 0.80 Mt N_2O from fertilizer consumption, although these estimates are especially uncertain.

Figure 1.3 Methane emissions by source

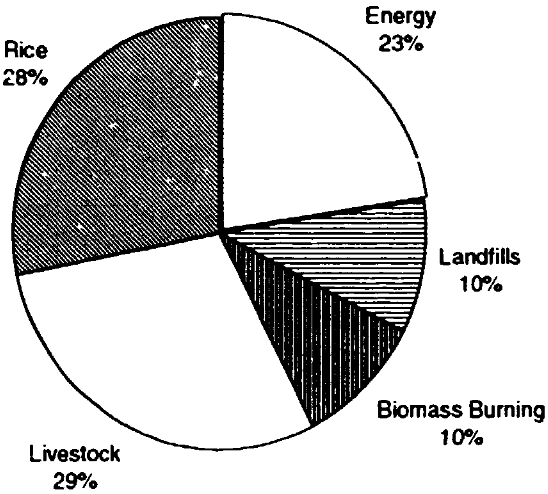
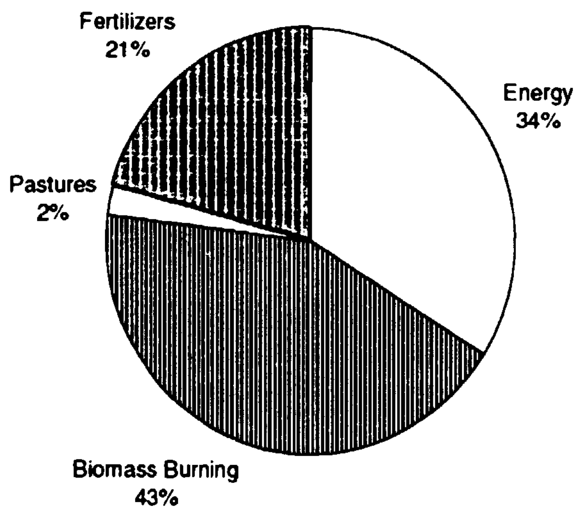


Figure 1.4 Nitrous oxide emissions by source



2 INDUSTRIAL EMISSIONS

2.1 Energy

Energy-related emissions are based on national energy accounts in the standard statistical literature (OECD/IEA 1990a, 1990b; United Nations 1990a). Emission factors for CO_2 are taken from ORNL (1990) and adjusted so that the fuel energy content on which the factors are based reflect net heating value, as used in the OECD/IEA statistics.[3] Non-CO_2 emissions from fossil fuel combustion were derived by applying emission factors for CO, CH_4 and N_2O at the sector and, where available, subsector level (US EPA 1989a; Radian 1990; JAERI 1990)[4]. For the important road transport subsector, country-specific emissions factors are derived for heavy and light vehicles separately and further by diesel and gasoline fuel use. For renewable fuels, regional emission factors are applied to industrial/commercial and residential fuelwood use (US EPA 1989a). A global emission factor is used for N_2O from firewood (Cofer et al. 1991; Crutzen and Andreae 1990). Methane loss from natural gas transportation and distribution are calculated from "loss" data in OECD/IEA (1990a, 1990b) and recent studies for Australia, Germau and the United States (IPCC 1990a). Country-specific CH_4 emissions factors are used for coal mining for the

major coal producers, while regional emissions factors are used for oil and gas extraction (Barns and Edmonds 1990; ICF 1990b).

The CO_2 emission estimates derived here differ significantly from those reported in ORNL (1990) for a number of regions and countries. The ORNL inventory relies exclusively on U.N. energy data, while this study relies on OECD/IEA (1990a, 1990b) for most countries (104 of the 142) and United Nations (1990a, 1989b) data for the remaining countries, all in developing regions (most in Africa). The OECD data includes information from private suppliers and other energy concerns, in addition to the sources compiled in U.N. statistics.

ORNL assigns global emissions factors by fuel type, while this study applies separate CO_2 emissions factors for combustion at the sector, and often subsector, level. In addition, unlike ORNL, this study assigns emissions from liquid fuel consumed in international marine bunkers to individual countries. Oil purchased by seagoing ships is assigned to the country of the port where fueling occurs. Also fuel combusted to generate electricity is assigned to the country that produces the power, not to the country that imports the electricity.

In addition, this inventory includes emissions from the combustion of fuel derived from "non-energy" uses, such as secondary petroleum products. This source may be substantial for a number of countries with extensive petroleum refining and chemical industries such as the Netherlands, which here is estimated to emit nearly 50 percent more CO_2 than recorded in the ORNL study.

As reported in the Annex, the energy sector accounts for 5.4 Gt of CO_2-C globally. This figure approximates ORNL's total for a comparable set of countries, although results for individual regions vary considerably.[5] The Soviet Union's and South & East Asia's emissions from energy are about 11 percent and 6 percent less than estimated by ORNL respectively. See Table 2.1 for comparisons.

Emissions from Latin America are about 3 percent less, and CO_2 release from Europe is almost 4 percent greater than the ORNL estimate. The most significant difference between the two studies at the regional level is the estimate for the Middle East, which is about 12 percent higher. At the country level, the deviation between the studies is more than 10 percent for about one third of the cases. See Table 2.2. The differences are greatest in Africa and in the Middle East. Table 2.3 compares the results of this study for non-CO_2 emissions to previous studies.

2.2 Cement

The inventory of carbon dioxide released from cement manufacturing relies heavily on the country inventories published by ORNL (1990). Carbon dioxide from this source is produced when calcium carbonate ($CaCO_3$) from limestone or other calcium-rich materials is heated to form lime, the main component of cement. Global emissions from this source are about 3 percent as great as emissions from energy use. Emissions are estimated by applying a global emission factor of 0.136 tonnes CO_2-C per tonne of cement produced (ORNL 1989) to international cement production data (US Bureau of Mines 1988; the United Nations 1990b). The emission factor is based on the mean variation in lime content (calcium oxide), which ranges from 60 to 67 percent by weight.

2.3 Halocarbons

Halocarbon emission estimates are calculated on the basis of historic production data from UNEP (1990) from a compilation of data from private sources assembled by EPA (Ebert 1990) and functions representing the lag between production and halocarbon emissions (ICF 1990a) were applied to these data. The analysis covers ten halocarbons, including CFCs, HCFCs, and halons controlled under the Montreal Protocol.[6] CFC-11, CFC-12, and CFC-113 together are responsible for about 90 percent of the warming contribution from this family of compounds. CFC-11 and CFC-12 are used in refrigeration systems, as blowing agents for foams, and in aerosol propellants. CFC-113 is employed exclusively as a solvent. Most of the remaining warming contribution is from CFC-114 and CFC-115, which are used in refrigeration,

[3] Energy statistics are given on either a "Net heating value" (NHV) or "Gross-heating value" (GHV) basis. The latter yields energy contents per unit weight or volume of fuel that are 5-10 percent larger, and emission factors based on GHV are correspondingly 5-10 percent less than those based on NHV. UN statistics, which are used by ORNL, can be either NHV or GHV, depending on the fuel.

[4] N_2O emissions factors from fossil fuel combustion were based, where available on Yasukawa (JAERI 1990). The factors are thought to provide a reasonable upper bound for emissions from stationary sources (McSorley 1990) whereas other N_2O emission factor estimates have been shown to greatly overestimate N_2O release due to an error in the gas collection and storage procedure used in laboratory tests (Muzio and Kramlich 1988; Montgomery et al. 1989; Linak et al. 1990). For mobile sources Yasukawa appears to provide consistent factors reflecting the effect of catalytic converters on emissions (JAERI 1990).

[5] However, ORNL's global estimate which, unlike the ORNL country estimates includes emissions from international marine bunkers, is 5.7 Gt CO_2.

[6] Emissions from Halon-2402 were omitted because of lack of information on global warming potential. It is a compound chiefly used in Eastern Europe. UNEP (1990) lists 1986 "production/use" of this compound at 3.0 kt, less than a third of global production/use of the other controlled halons.

Table 2.1 Comparison of CO_2 release from energy consumption and production by regions in 1988 (Mt CO_2-C)

	ORNL (1)	This study (2)	% Difference between studies (2-1)/(1)
World[a]	5514[b]	5399	-2.1
North America	1418	1406	-0.8
Europe	1176	1218	3.6
JANZ	331	327	-1.2
USSR	1067	951	-10.9
Centrally planned Asia	629	615	-2.3
South and East Asia	327	308	-5.6
Middle East	157	176	12.4
Africa	163	160	-1.8
Latin America	247	239	-3.2

[a]Total of 140 countries: the 142 covered in G2S2 less Taiwan and Lesotho, which are not covered in ORNL.
[b]ORNL global estimate, which includes emissions from marine bunkers, is 5743 Mt CO_2-C, 5 percent greater than the total for 145 countries.

Table 2.2 Difference between emissions estimates by country (number of countries in each grouping)

	<6%	6-10%	>10%
World	62	25	52
North America	1	1	0
Europe	15	5	6
JANZ	2	0	2
USSR	0	0	1
Centrally planned Asia	3	2	0
South and East Asia	6	5	6
Middle East	5	2	9
Africa	20	1	24
Latin America	10	9	4

Table 2.3 Comparison of energy-related CO, CH_4 and N_2O global emissions estimates

	This study	Previous studies	
CO (Mt CO-C)			
Fossil combustion	169	170 - 430	US EPA 1989a
Firewood	43		
CH_4 (Mt CH_4)			
Fossil combustion	1.8	1.3[a]	Barns and Edmonds 1990
Firewood	3.1	1.5 - 7.3[b]	Crutzen and Andreae 1990
Coal mining	49.0	19 - 50	IPCC 1990b
Oil extraction	7.6		
Nat. gas extraction	4.1	3.8 - 30	Barns and Edmonds 1990
Nat. gas trans. & dist. losses	13.4	16.1	Barns and Edmonds 1990
N_2O (Mt N_2O)			
Fossil combustion	1.2	0.5 - 1.4	IPCC 1991
Firewood	0.2		

[a]Automobile exhaust emissions only
[b]Estimate for firewood burning in the tropics

and the halons -- H-1211 and H-1301 -- which are used in fire extinguishers (US EPA 1988). In addition, two CFC feedstock chemicals with significant radiative properties, methyl chloroform (CH_3CCl_3) and carbon tetrachloride (CCl_4), are included in the inventory. The inventory includes the CFC substitute HCFC-22, which is used as a refrigerant or as a blowing agent and has significant radiative heat-forcing characteristics (Dupont 1988).

While country-specific information on halocarbon production (CFCs, halons and HCFCs) have been compiled formally by the United Nations Environment Program (1990) since the passage of the information exchange agreement in the 1985 Vienna Stratospheric Ozone Agreement, data quality is limited due to incomplete and aggregated reporting by Montreal Protocol signatories.[7]

Current emissions of most halocarbons are 30 - 50 percent lower than current production due to the delay in release. CFCs used in aerosols, as solvents, or in blowing foams are released without significant delay, while compounds used for refrigeration are released over about four years on average if used in mobile air conditioning units, or over about twenty years if used in large, sealed refrigeration systems. The lag between production and release of halons, which are used in fire fighting or leaks from fire control systems, can be thirty years or more. These delays are taken into account in halocarbon emission estimates by applying lag factors to end-use application shares for the major compounds (ICF 1990a). Because of the reduction requirements of the Montreal Protocol and more stringent country phaseout schedules, CFC production was 40 percent lower in 1991 than in 1986 (TEAP 1991). In addition, there's strong recent evidence that the indirect effects of halocarbons in the atmosphere may greatly reduce the net global heating effect of these gases (Ramaswamy et al. 1992). Halocarbon emissions estimates are presented in Table 2.4 where they are compared to estimates of halocarbon production.

[7]As of mid-1991, more than 70 countries had agreed to phase out halocarbons under the terms of the treaty, which seeks to protect the stratospheric ozone layer form ozone-depleting substances. As most halocarbons are also greenhouse gases, the Protocol will have an important effect on the level of greenhouse gas emissions.

Table 2.4 Global CFC and halon emissions and production (kt of compound)

	CFC-11	CFC-12	CFC-113	H-1301
Emissions[a]				
This study	290.6	359.9	152.3	3.0
Production/Use[b]				
UNEP 1990	385.3	464.1	220.7	11.6
EPA 1989	425.5	483.7	211.2	9.3

[a]1985 data
[b]1986 data

3 LANDFILLS

Methane emissions from landfills are computed as the product of solid waste generated, fraction landfilled, waste carbon content, and carbon fraction converted to gaseous form. The methodology draws on the work of Bingemer and Crutzen (1987) who compiled data on municipal solid waste (MSW) per capita, fraction landfilled, and degradable organic carbon content of waste.[8] For Europe, Japan, North America, and several developing nations, more recent country-specific data on waste generation rates, disposal methods, and waste compaction are incorporated (Carra and Cossu 1990; Piccot et al. 1990). MSW generation is assumed to be restricted to urban populations (United Nations 1989).

It is assumed that 80 percent of degradable organic carbon in landfills is converted to biogas containing about 50 percent CH_4 by volume (Bingemer and Crutzen 1987). But as carbon dissimilation depends on landfills conditions, e.g. the extent to which the landfill is sealed from the air and the amount of moisture in the landfill; this rate varies from site to site. A recent survey suggests that this dissimilation rate may be an overestimate because it is possible that CH_4 oxidation only takes place in the upper aerobic layers of the landfills (Schuetz et al. 1990). Additional uncertainties in flux estimates are due to lack of information on average moisture content of the landfill environment, nutrient availability -- which is essential for the survival of methanogenic bacteria -- and leachate pH, as low leachate pH can create a highly acidic environment, which decreases CH_4 production (Pacey and DeGier 1986). These effects can be considerable; a recent study of twenty landfills found that the "wet" sites generated about 2.6 times more CH_4 than the "dry" landfills (Thorneloe 1990).

The estimate presented here of 36 Mt CH_4 from landfilled wastes is at the lower end of Bingemer and Crutzen's (1987) range of 30-70 Mt CH_4, because recent information indicates that developed countries landfill a lower fraction of municipal solid waste and that fewer people live in urban areas in developed countries than assumed by Bingemer and Crutzen (Carra and Cossu 1990; United Nations 1989a). It is

[8]Degradable organic carbon depends on the type of refuse only. For example, paper and wood products contain more carbon per ton than do "wet" organic wastes.

considerably higher, however, than a recent study that holds that most disposed carbon will eventually remain in the ground as a sedimentary carbonaceous deposit, and that CH_4 composes only 20 percent, rather than 50 percent, of the carbon in landfill gas (Richards 1990). See Table 3.1 for a comparison of the varying assumptions used in these studies.

4 BIOTA

Several previous studies have estimated net CO_2 release from deforestation, although chiefly at the regional or global levels. See Table 4.1 for comparisons. This study estimates CO_2 release at the country level and, in addition, includes CO, CH_4, and N_2O emissions from biomass burning, as well as an inventory of CO_2 sequestration in plantations, commercial forests, and wood products. The estimates in this study for net annual CO_2 release from deforestation fall in a range of 1.3 to 2.1 Gt CO_2-C. This estimate reflects a reasonable -- but by no means certain -- set of land clearing data, biomass levels, and soil carbon release rates assumptions. Our interpretation of the available data suggests that CO_2 emissions from land clearing are most likely to be about 1.4 Gt CO_2 and that a reasonable estimate of CO_2 sequestration due to forest management and forest products is approximately 0.5 Gt CO_2. Consideration of both anthropogenic CO_2 sinks and deforestation, therefore, yields a net CO_2 release of about 0.9 Gt CO_2 annually.

4.1 *Aboveground Biomass*

Country-specific deforestation rates are based on Myers' study[9] of 34 countries in the tropics (Myers 1989), supplemented by a recent report on closed forest clearing in Brazil (Fearnside et al. 1990). The Myers' survey does not entail original satellite surveillance or ground-truthing research, but synthesizes reports and surveys from public and private sources, along with information on migration and settlement patterns. As it was completed fairly re-

[9]Myers' clearing estimates for tropical forests were assigned to the closed and open forest categories according to the proportion of deforestation taking place in these forest types as estimated by the FAO in 1981.

Table 3.1 Methane release from landfills

	Waste generated (kg/capita/day)	Landfilled (%)	DOC[a] (%)	Urban pop. (mil.)	Total CH_4 Release[b] (Mt CH_4)
	(A)	(B)	(C)	(D)	
This Study					
US & Canada	1.6	80	21.0	210	11
Other OECD	1.0	66	19.0	380	9
USSR & E. Europe	0.6	87	17.0	250	4
DCs	0.5	80	13.0	1154	12
				Total	36
Bingemer & Crutzen (1987)					
US & Canada	1.8	91	22.0	272	19
Other OECD	0.8	71	19.0	471	10
USSR & E. Europe	0.6	85	17.5	400	7
DCs	0.5	80	15.0	736	9
				Total	45[c]
Orlich (1990)					
MDCs	1.0	100		900	27[d]
DCs	0.5	100		1100	4[d]
				Total	31

[a]DOC = Degradable Organic Carbon.
[b] Total CH_4 release = (A) x (365) x (B) x (C) x (80 % dissimilated) x (D) x (50 % C as CH_4) x (16/12 conversion, C to CH_4) x (1000, conversion to tonnes).
[c]An additional 14 Mt CH_4 was reported for industrial waste.
[d]Dissimilated fraction assumed to be lower than 80%.

cently, it provides a more current view of tropical deforestation at the country level than the last Tropical Forest Assessment published a decade ago by the FAO (FAO/UNEP 1981). For the tropical countries not included in the Myers study, we used the forest clearing rates reported in the 1980 FAO assessment (FAO/UNEP 1981), adjusted so that the countries summed to the higher regional deforestation totals provided in the FAO's preliminary report of the 1990 Tropical Forest Assessment (FAO 1990). Table 4.2 compares the land clearing estimates offered in the 1990 FAO report with the 1980 FAO survey, and with a recent report by the World Resources Institute (WRI 1990). Data on changes in forest area for countries not covered in the tropical forest assessments come from disparate sources (Waddell et al. 1989; ECE/FAO 1985; Chinese Ministry of Forestry 1990; FAO Production Yearbook 1987b).

Biomass levels on cleared land are derived from "wood volume" or "volume over bark" calculations (Brown et al. 1989; Brown and Lugo 1984), which estimate biomass at about half the level reported through the "destructive sampling" method. The latter method involves on-the-ground weighing or measuring of living biomass and litter, while the wood volume approach entails applying expansion factors (ratios of aboveground to commercial biomass) to estimates of the standing volume of the trees. The net change in biomass is the difference between the forest biomass removed and the biomass retained after forest conversion, e.g. in cropland or pasture. Post-conversion biomass is taken at five tonnes carbon per hectare (Houghton 1991). While harvest data and expansion factors are sources of considerable uncertainty, the wood volume method improves on existing destructive sampling estimation which may be flawed by small sample size and unrepresentative site selection (Brown et al. 1989).

Emissions of CO, CH_4, and N_2O from land clearing depends on the fraction of biomass in forests that is burned rather than removed for wood products or left on the ground to decay. It is assumed that, including repeat fires, 40 percent of the above-ground biomass in tropical closed forests, and 50 percent in open forests, is burned (Fearnside 1991). Based on fraction of combusted carbon by volume, the emission factors used are CO: 8.0 percent and CH_4: 0.8 percent (Crutzen and Andreae 1990). These factors take account of the 6 to 16 percent of carbon that is converted to charcoal or soil carbon, and thus not released into the atmosphere (Crutzen and Andreae, 1990). Emission factors for N_2O are based on recent in situ measurements over a large prescribed fire (Cofer et al. 1991). All the selected factors, however, are estimates of global averages and may fail to capture variations that depend on site-specific parameters such as biomass moisture content and microclimatic conditions (Kauffman 1990).

To estimate the total CO_2 release from deforestation, it is assumed that all of the biomass not exposed to fire decays into CO_2, save for the fraction that becomes incorporated into soil as elemental carbon and the portion of wood removals that are converted into long-lived forest products. The fraction of decaying wood that remains as elemental carbon is about 5 percent (Boston 1990). In this study, long-lived wood products, including sawn wood (boards, sleepers, railroad ties, etc.) and wood-based panels (veneer sheets, plywood, and particleboard, etc.) are credited according to national wood products production. Wood products were estimated to sequester about 0.1 Gt CO_2, approximately 10 percent of the net anthropogenic biotic flux of 0.9 Gt CO_2 annually.

Table 4.1 Global annual emissions from land use changes excluding afforestation (Gt CO_2-C)

	Biomass burning	Biomass decay	Soils	Total global release
This study[a]	0.5 - 0.7	0.6 - 1.0	0.2 - 0.4	1.3 - 2.1
Houghton 1991				1.1 - 3.6
Crutzen and Andreae 1990				0.5 - 3.4
World Resources Institute 1990				2.8
Bouwman 1990			0.2 -0.9	
Myers 1989				2.0 - 2.8
Detwiler and Hall 1988				0.4 - 1.6
Peng 1986[b]				0.5
Houghton et al. 1983				1.8 - 4.7

[a]High end of range is based on destructive sampling estimates of aboveground biomass and higher soil carbon release rates (25% release). Low end is based on wood-volume estimates of biomass levels and lower soil carbon release rates (15%).
[b]Based on ratio of carbon 13 in tree rings.

Table 4.2 Annual land clearing in the tropics (million hectares)

	This study[a] & FAO (1990)	WRI (1990)[b]	FAO (1981)
Americas	7.30	10.91	5.65
Africa	4.80	1.36	3.71
Asia	4.70	3.98	1.97
Total	16.80	16.25	11.33

[a]Based on Myers (1989), FAO/UNEP (1981), FAO (1990) and Fearnside et al. (1990).
[b]Closed forest only.

At 44 Mt CO-C, 6 Mt CH_4, and 0.24 Mt N_2O, biomass burning related to deforestation represents only a small fraction of annual anthropogenic emissions of these gases. Emissions from savanna fires, agricultural residues, shifting cultivation and prescribed burning are the source of considerably greater volumes -- approximately 230 Mt CO, 30 Mt CH_4, and 1.35 Mt N_2O[10] (Crutzen and Andreae 1990). These figures were derived from Crutzen and Andreae's estimates by adjusting the mid-point in their ranges to take into account overlap with emissions from firewood and permanent deforestation, and for the slightly lower N_2O emission factor used (Cofer et al. 1991; Andreae 1991). The estimated emissions of CO and N_2O roughly approximate the release of these gases from fuel combustion.

Periodic biomass burning, as opposed to burning for land clearing, represent important sources of the trace gases that are the by-products of incomplete combustion, i.e. CH_4, CO, and N_2O; this activity does not represent a significant net source of CO_2 because the vegetation or crops are allowed to regrow, and eventually store the same amount of CO_2 that was previously released.[11]

Greenhouse gas emissions from biotic sources, apart from deforestation, were estimated on the regional rather than the country level because of lack of data. Emissions from biomass burning were assigned using Crutzen and Andreae's (1990) estimate of carbon combusted in different categories of biomass burning. Grassland burning, shifting cultivation and agricultural residue burning are each assumed to contribute about 30 percent of emissions from these sources, with prescribed burning making up the remaining 10 percent. The grassland fraction is assigned to Africa and estimated emissions from this region approximate those from a recent study placing CH_4 emissions from African grasslands at about 10 Mt CH_4 (Delmas et al. 1991). Emissions from shifting cultivation are allocated to Latin America, and it is assumed that 90 percent of agricultural residue burning takes place in developing countries (Crutzen and Andreae 1990). Residue burning within developing and developed regions is distributed according to the area devoted to agricultural crops (FAO 1987b). Emissions from controlled or prescribed forest fires are assigned to North America and JANZ (Japan, Australia, New Zealand) only (Crutzen and Andreae 1990).

4.2 Soils

Soils disturbed through land clearing release significant amounts of CO_2 and may be an important source of anthropogenic N_2O. Estimates of soil carbon loss after clearing are based on area cleared and country-specific soil carbon inventories. The soil carbon stock is based on an analysis of several thousand carbon content profiles (Post et al. 1982) that Richards et al. (1983) compiled into biome and country-specific soil carbon estimates. Most of the CO_2 from soil carbon is released during the first five years after clearing (Houghton 1991). In this study, CO_2 release is treated as instantaneous. These assumptions yield a range

[10]The uncertainty associated with these estimates is at least 100 percent. Another recent study offers estimates for emissions from grasslands only, suggesting that about 3,690 Mt of biomass is burned each year, releasing 12 - 28 Mt CH_4 and 100 - 205 Mt CO (Hao et al. 1989). A study based on carbon isotope ratios of atmospheric methane rates places CH_4 flux from biomass burning at ~60 Mt CH_4, the high end of Crutzen and Andreae's range (Quay et al. 1991).

[11]The post-oxidation CO_2 component of CO and CH_4 is excluded when we calculate the comparative warming effect (CO_2-equivalence) of emissions from the "renewable" CH_4 and CO sources, including biomass burning, fuelwood, landfills, rice cultivation, enteric fermentation and animal wastes. As the carbon emitted from these sources is eventually taken up through photosynthesis, the net heating effect is the heating effect of CH_4 and CO net of the CO_2 warming contribution.

of CO_2 emissions from soils in all countries at between 0.2 and 0.4 Gt CO_2-C.

Soil N_2O emissions estimates are based on measured flux rates from forests converted to pastures in the Amazon basin. A study of N_2O emissions from pastures in the Amazon found a flux rate roughly three times higher than from undisturbed tropical forests (Luizao et al. 1989); in contrast, the N_2O flux from sites where forests had been burned half a year earlier indicated no elevation in the flux rate (Matson et al. 1990). The net N_2O flux estimate of 0.38 g N/m²/year is used for conversion to pasture because in preparing this estimate Luizao et al (1989) took records of N_2O emissions on a continuous basis during both the wet and dry seasons. The cause of the enhanced flux rate, which remains elevated for at least one decade, is unknown (Matson 1991). Possible mechanisms include altered soil aeration from compaction and changes in oxidizable carbon under grass versus under forest vegetation (Matson et al. 1990). The estimates of forest converted to pasture considered for this study are based on changes in land area in Amazon Basin countries between 1975 and 1985 categorized as permanent pasture (FAO 1986). The resulting estimate of 0.08 Mt N_2O from disturbed soils in the tropics, however, is very uncertain. Emissions are believed to vary between ecosystems, sites within ecosystems, and points within sites (Matson and Vitousek 1990), and may increase with temperature, water content and pH (Van Breemen and Feijtel 1990). The change in N_2O flux is assumed for the Amazon region only because the enhanced flux may not be generalizable to all tropical pastures (Garcia-Mendez 1991).

While more N_2O flux measurements have been completed in developed countries than in the tropics, the net anthropogenic flux in developed countries may be more uncertain because, due to earlier development, the extent of perturbation from natural conditions is not known. In addition to the absence of baseline data, the range of measured "post-conversion" fluxes is greater; the net N_2O flux resulting from temperate forest conversion to pastures ranges from 0.06 to 4.79 g N/m²/year, and conversion from forests to woodlands and grasslands varies from -0.11 to +0.12 g N/m²/year (Galbally 1985). For these reasons, this study does not include N_2O emissions from land use changes in temperate regions. Emissions of N_2O from nitrogenous fertilizer applications are discussed in a later section.

4.3 Terrestrial Sinks

Tree growth is tracked here by considering the two most quantifiable components of net photosynthetic uptake of CO_2 -- commercial wood growth in temperate regions and tree plantations in China and the tropics. Commercial wood growth is identified with the net annual increment of wood and bark volumes in standing forest stock (ECE/FAO 1985). An "expansion factor" is applied to account for biomass such as leaves and twigs that are not included in the commercial wood volume increment. In addition, wood volumes are converted to mass units and average national carbon densities are applied based on statistics provided by the ECE/FAO (1985). The largest commercial forest "sinks" of CO_2 are found to be in North America, Europe, and the Soviet Union. Forests in these regions may take up almost 0.3 Gt carbon per year, about 20 percent of estimated CO_2 release from global deforestation (see Table 4.3). In order to avoid double counting, harvested wood was subtracted from the annual wood growth statistic (net of the "long-term" wood product category explained above).

Developing country afforestation is associated with tree plantations establishment. CO_2 sequestration is computed as the product of tropical plantation areas (FAO 1981) and an average net annual uptake rate that is assumed to be 5.2 tonnes carbon per hectare per year (Brown et al. 1986; Farnum et al. 1983). The net CO_2 uptake estimated here may be considered an upper bound because, due to lack of information, it does not take into account the maturity of the trees in the plantations or the type of harvest planting rotation used. Both of these factors can influence net CO_2 uptake.

For China, estimates are based on afforestation statistics since 1949 including natural forests (3.4 million hectares) and plantations (38.3 million hectares) (Chinese Ministry of Forestry 1990). Natural forests are assumed to sequester 2.0 tonnes of carbon per hectare per year and tree plantations 4.2 tonnes per hectare per year (Marland 1988). Net annual CO_2 uptake is estimated to be about 0.1 Gt, about 15 percent of China's CO_2 release from fossil fuels. Subtractions of harvested wood also resulted in an estimate of about 0.1 Gt net sequestration.

5 AGRICULTURE

5.1 Rice

Methane emissions from rice cultivation is computed as the product of area under wet rice cultivation, the growing period, and an average daily CH_4 emission rate. About 85 percent of the area devoted to rice paddies world-wide is under wet rice cultivation, with the remaining area devoted to dry or "upland" rice cultivation (IRRI 1988). The growing period, or number of days rice is grown in a given area each year, is directly correlated with emissions because methane is produced by methanogenic bacteria in the flooded fields and is released by diffusive transport through the rice plants to the atmosphere. The total growing

period is derived from seasonal crop calendars of major rice-producing countries (Matthews et al. 1991). The period may include more than one crop, as multiple cropping is common in Asia.

Methane emission factors for temperate and tropical countries are based on a continuous record of CH_4 emissions from Italian rice paddies over several complete vegetation cycles under different fertilizer regimes (Schuetz et al. 1989a). The selected emission factor for tropical countries is nearly identical to the mid-range estimate from field measurements in China (Schuetz et al. 1989b). Methane escapes throughout the growing season, although the magnitude of the seasonal methane flux varies considerably. The emission rates were based on seasonally-averaged emission rates recorded in the Italian rice paddies adjusted by the observed temperature dependence of the CH_4 emission rate. This methodology, derived from methane flux/soil temperature relationships, was used to develop daily emission rates for tropical climates during the wet and dry seasons, as well as for temperate climates (Schuetz et al. 1989a).

The resulting annual global emissions of 98 Mt CH_4 from wet rice cultivation is higher than earlier estimates of 59 Mt CH_4 (Cicerone and Shetter 1981) and 47 Mt CH_4 (Seiler et al. 1984) which are based on discontinuous CH_4 flux measurements. Comparative estimates from more recent studies are presented in Table 5.1. It should be noted that preliminary studies of emissions from rice paddies in China suggest that about 100 Mt CH_4 may be produced annually from this source alone (Schuetz et al. 1990; Khalil and Rasmussen 1991). On the other hand, a recent study by Neue (1990) proposes that, due to soil characteristics and water regimes, only a fraction of the world's wet rice fields may yield significant amounts of methane leading to a global flux of only 21 - 52 Mt CH_4 annually.

With the exception of the Neue study, the wide range of estimates is due largely to the variation in measured CH_4 emission rates. Emission rates have been found to vary with season, time-of-day, fertilizer type, mode of application and soil temperature (Cicerone et al. 1983, Holzapfel-Pschorn and Seiler 1986, Cicerone and Shetter 1981, Schuetz et al. 1990, Yagi and Minami 1990). Sensitivity to these variables can be considerable; for example, measurements collected at a Japanese test site revealed a flux rate that varied by a factor of forty. More accurate estimates will require a better understanding of these factors and additional variables such as soil type, pH, and redox potential (tendency for oxidation and reduction to take place) (Neue el at. 1990; Yagi and Minami 1990).

5.2 Livestock

Emissions from livestock may be the single most important anthropogenic CH_4 source (see Figure 1.2). About three-quarters of livestock emissions, or 75 Mt CH_4 of the 103 Mt total, are believed to be due to enteric fermentation with the remainder from decomposing animal wastes. Methane emissions from enteric fermentation are computed by applying average CH_4 emission factors by animal type (Crutzen et al. 1986) to livestock population estimates for 1988

Table 4.3 Terrestrial carbon sinks: Annual tree growth and forest products (Mt CO_2-C)

Region	Net forest carbon uptake[a]	Forest products sequestration[b]
North American	111	37
Europe	41	21
JANZ	0	-1
USSR	118	23
Centrally Planned Asia	112	6
South and East Asia	36	10
Middle East	0	0
Africa	22	2
Latin American	49	8
Total	489	106

[a]Estimated net carbon uptake in plantations and commercial forests.
[b]Estimated carbon sequestration in sawnwood and panels less imported pulps.

(FAO 1991). About three-quarters of the CH_4 produced by enteric fermentation is released by beef cattle and dairy cows. Other ruminating animals included in this inventory are buffalo, sheep, goats and camels. Non-ruminant domesticated animals that contribute to methane emissions -- including pigs, horses, mules, and asses--are also reflected in the accounts. Methane generation per head of cattle is about 50 percent higher in developed countries due to higher body mass and feed intake. The average emission per animal also varies with the makeup of the animal population (e.g., the ratio of mature to immature animals) and the digestibility and type of animal feed. The uncertainty in estimating emissions factors for a given animal population is compounded in developing countries where animal husbandry practices are less well documented. The digestibility of feed is believed to vary by about 50 to 90 percent and the level of energy intake to range from 100 percent to 300 percent of the animal's metabolic maintenance requirement (Blaxter and Clapperton 1965). In addition, methane yields may differ by about 15 percent, according to the adequacy of ammonia levels in the rumen of animals with relatively poor diets (Preston and Leng 1987). Despite these ranges, the uncertainty of CH_4 release from enteric fermentation has been estimated at only about 15 percent (Crutzen et al. 1986).

Methane arises from animal wastes when the manure is maintained under anaerobic conditions. The emissions level depends on the amount of manure produced -- which varies with diet and animal mass. Emissions are the product of animal populations (FAO 1986) and an emission factor which, in turn, is the product of manure production, the volatile organic solid component of manure i.e. the amount of (i.e. the amount of degradable organic material) and the methane conversion rate (Casada and Safely 1990). The conversion rate varies with diet, climate, and waste treatment method.

This inventory draws heavily from the work of Casada and Safely (1990) who computed methane emission rates by country based on estimates of regional livestock feeding practices and the relative use of various types of waste management systems. Treatment through waste lagoons is the most methane-productive waste handling system; pasture, and drylot disposal lead to much lower levels of CH_4 release. Casada and Safely argue that the primary uncertainty is due to insufficient information on the frequency of various waste management systems and due to the lack of field measurements of individual waste management procedures. If it is assumed that less than 10 percent of animal wastes undergoes anaerobic digestion, as proposed by Verma et al. (1988), emissions would total about half of Casada and Safely's estimate of 28 Mt CH_4, suggesting an uncertainty range on their estimate of about 50 percent.

5.3 Fertilizer

Nitrous oxide emissions from fertilizers are estimated by applying N_2O emission factors to nitrogenous fertilizer consumption data for ten fertilizer

Table 5.1 Methane release from wet rice cultivation

	Area (10^{10} m^2)	Vegetation period (days/year)	Emission rate ($g/m^2/day$)	Total emissions (Mt CH_4)
This study				
temperate[a]	5	135	0.44	3
tropical[b]	121	136	0.58	95
				Sum 98
Schuetz et al. 1989				
temperate[a]	5	120 - 150	0.28 - 0.59	
tropical[b]	140	75 - 150	0.24 - 0.80	
				50 - 150
Neue et al. 1990	80	130	0.20 - 0.50	21 - 52
WRI 1990	122	140	0.39	66

[a]Temperate regions: Europe, United States, and Japan.
[b]Tropical regions: Asia, Africa, and Latin America.

types by country[12] (FAO 1987a; FAO 1988a; US EPA 1989). Fertilizer types include ammonium sulphate, ammonium nitrate, ammonium phosphate, sodium nitrate, calcium nitrate, calcium cyanide, urea, "other nitrogen fertilizers," "other complex fertilizers," ammonium phosphate, and anhydrous ammonia.

Emissions factors are taken at the median estimates that Eichner (1990) compiled on the basis of data from 24 primary articles covering 104 investigations of emissions in 9 locations using closed-chamber techniques. The emission factors cover each of five classes of fertilizers: ammoniums, nitrates, urea, anhydrous ammonia, and "other." Emission factors, expressed as a percentage of the applied nitrogen emitted as N_2O, vary from 0.03 percent for nitrate compounds to 1.63 percent for anhydrous ammonia (Eichner 1990). The factors take into account N_2O loss during the first season after fertilization only and do not consider controlling factors such as variations in temperature, soil conditions, mode of fertilizer application or the intensity of rainfall and irrigation regime (US EPA 1989a). The uncertainty in emission factors is quite large: a factor of 8 for anhydrous ammonia, 45 for the ammoniums, 43 for ammonium nitrate, 2.5 for urea, and 500 for the nitrate group (Eichner 1990; Mosier et al. 1986; Mosier and Bronson 1990). Agricultural practices that affect emissions include fertilizer application, tillage and irrigation practices, and crop type (Sahrawat and Keeney 1986). Relevant environmental factors include temperature, precipitation, pH, microorganism populations, and freeze and thaw cycles. In addition, variation in soil type may be even more important in determining N_2O emissions than the type of fertilizer applied (Byrnes et al. 1990).

The emissions estimate calculated here of 0.8 Mt N_2O is on the lower end of the likely range from nitrogenous fertilizers. Additional factors may increase N_2O flux above these levels. For example, N_2O from fertilizers may leach from fields into groundwater or irrigation systems (Ronen et al. 1988), to be released when the water reaches the surface; and fertilized soils planted with leguminous crops may release N_2O at greater rates than assumed here. Leguminous crops and groundwater may each produce as much N_2O as is released directly from the fertilizers (Eichner 1990; Minami and Ohsawa 1990; Conrad et al. 1983). Corroborative evidence of the importance of fertilizer-related emissions appears in a recent study of snow nitrate levels measured in Antarctica that suggests that nitrate levels rose sharply beginning in the late 1950s when nitrogen fertilizer consumption was widely introduced (Turner 1991).

6 CONCLUSIONS

Greenhouse gas emissions accounts by country offer a baseline for setting future emissions targets and for monitoring trends. Country-level accounting refines global estimates of anthropogenic emissions by relying on more detailed information on activity levels and emissions factors. In addition, greenhouse gas emissions accounts by country provide a basis for assigning responsibility for emissions. The national inventories offered here, while comprehensive in scope, are not intended to describe nations' relative responsibility for the increase in concentration of greenhouse gases in the atmosphere. This would require defining a responsibility measure (for example, per capita emissions), an approach for treating difficult-to-measure emissions sources, and an equivalence index for comparing the relative warming effect of the different greenhouse gases. Furthermore, criteria other than current emissions -- such as historical emissions -- may be relevant when judging national contributions.

The accounts covers 142 countries, 5 greenhouse gases and 8 major anthropogenic sources. The emission estimates by gas and source fall within the global range cited by the IPCC (IPCC 1990; IPCC 1992). This inventory includes a new estimate of CO_2 from fossil fuel combustion using primarily International Energy Agency data. Our total is within 2 percent of Oak Ridge National Laboratory's (ORNL 1990) group total for the 140 countries common to both studies. The biotic component of CO_2 has been calculated at a net 0.9 GT CO_2-C, the difference of 1.4 GT released from tropical deforestation and about 0.5 GT C sequestered through afforestation, tree growth in commercial forests and forest products. The tree growth data we converted in this study to carbon uptake estimates involves a number of uncertainties but points to a potentially significant CO_2 sink component in Europe, North America, and China.

Methane emissions from energy production and distribution is estimated at 79 Mt CH_4, approximating the lower bound of the range 80-120 Mt CH_4 derived from studies of the concentration of the C isotope of "fossil" CH_4. Emissions from rice cultivation are calculated at 98 Mt based on CH_4 emission rates from field tests of paddies in Asia. The global total calculated is on the high end of global estimates published in the current literature. Recent studies suggest that emissions may actually be lower because of affecting factors in the soil matrix. Of the anthropogenic CH_4 sources, rice paddies are the

[12]Nitrogen fertilizer may in addition increase net CH_4 emissions by decreasing the rate at which soils take up methane from the atmosphere (Mosier et al. 1991), a process not included here due to lack of data.

most uncertain. The CH_4 total from livestock includes 76 Mt CH_4 from enteric fermentation and 28 Mt CH_4 from animal wastes. The country estimates are likely to be refined considerably in the near term as information on livestock breeding, diet, and waste management are being incorporated into ongoing studies of CH_4 emission factors for different regions.

Our estimate of CO emissions from fossil fuel and biomass combustion is within of the range offered by the IPCC based on Khalil and Rasmussen (1990). For the N_2O component of fossil fuel and biomass emissions, we approximate the upper bound cited by the IPCC (1990b; 1992), and at the low end of the IPCC range for emissions from fertilizer consumption. Considering all of the anthropogenic sources described above, we calculated the relative heating contribution of the gases studied using the IPCC's global warming potential for a 100 year period (IPCC 1990) is: CO_2: 61 percent; CO: 8 percent; CH_4: 17 percent; N_2O: 3 percent; halocarbons: 11 percent.

The emission accounts reveal significant variations in emissions across regions and countries:

- industrialized regions release more than half of global anthropogenic emissions of CO_2 and halocarbons, while developing regions release over half of CO, CH_4, and N_2O emissions.
- industrial countries account for over half the emissions from fertilizers, cement, halocarbons, landfills, and energy (all gases), while developing countries dominate emissions from rice cultivation, biomass burning, livestock, and deforestation.
- sixty percent of the methane from fossil fuels production comes from just three countries, the USA, China, and the former Soviet Union.
- about half of the annual CH_4 emissions from rice cultivation are released in China and India.
- emissions from livestock tend to be more evenly distributed among regions and countries than emissions from all other GHG sources.
- Asia releases about two thirds of all methane from the developing world because of importance of rice cultivation, but only one quarter of CO emissions, because of the higher rate of forest and savanna burning in Latin America and Africa.
- two-thirds of N_2O from fertilizers were found to be released in just two countries - - the USA and China -- which are major consumers of the fertilizer types thought to evolve into higher levels of N_2O release.
- estimates for CO_2 emissions from fossil fuel combustion for more than one third of the countries we considered differed from the ORNL country estimates by more than 10 percent.

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Annex

Greenhouse Gas Emissions Inventory

- Total Current Emissions by Gas
- Energy and Industry
- Halocarbons
- Landfills and Biota
- Agriculture

TOTAL CURRENT EMISSIONS BY GAS

REGION / COUNTRY	CO2 (kT C)	CO (kT C)	CH4 (kT)	N2O (kT)	CFCs (kT CFC-11 equiv.)
WORLD TOTAL	**6,431,861**	**485,575**	**352,398**	**3,783**	**1,369**
NORTH AMERICA	1,277,925	87,499	38,357	901	397
CANADA	32,250	8,072	3,218	37	22
U.S.A.	1,245,675	61,028	32,739	756	375
EUROPE	1,192,206	45,657	38,025	381	453
ALBANIA	2,427	84	127	1	2
AUSTRIA	11,177	1,096	380	4	9
BELGIUM	31,524	901	633	6	18
BULGARIA	29,972	455	599	9	6
CZECHOSLOVAKIA	63,196	825	1,404	15	9
DENMARK	15,557	526	453	9	6
FINLAND	6,066	833	257	6	4
FRANCE	86,145	5,813	3,706	40	55
GERMANY	269,665	8,401	6,314	72	80
GREECE	20,286	509	508	8	6
HUNGARY	17,272	525	903	7	4
ICELAND	543	29	23	0	0
IRELAND	4,774	310	572	4	2
ITALY	106,641	3,578	2,133	27	57
LUXEMBOURG	2,499	86	57	1	0
NETHERLANDS	49,137	1,115	1,122	10	10
NORWAY	7,336	425	312	3	2
POLAND	121,654	2,091	5,653	32	19
PORTUGAL	7,341	419	278	3	6
ROMANIA	57,772	622	1,658	16	15
SPAIN	49,843	2,535	2,003	17	24
SWEDEN	7,009	1,717	281	6	6
SWITZERLAND	11,806	761	261	2	9
TURKEY	29,415	1,640	2,029	13	32
UNITED KINGDOM	154,252	7,278	4,934	44	56
YUGOSLAVIA	28,894	786	1,125	10	15
JANZ	339,446	19,186	10,925	119	165
AUSTRALIA	60,672	3,038	5,040	20	16
FIJI	310	25	17	0	0
JAPAN	273,801	8,890	3,539	57	146
NEW ZEALAND	4,663	333	1,429	2	3
USSR	829,486	17,491	33,350	260	139
CENTRALLY PLANNED ASIA	577,290	23,317	60,655	299	21
CHINA	494,048	12,895	52,396	228	16
KOREA, DPR	36,863	466	1,367	12	2
LAOS	31	76	331	0	0
MONGOLIA	2,444	71	375	1	1
VIETNAM	43,904	609	4,986	5	0
SOUTH & EAST ASIA	791,473	55,580	90,484	399	72
BANGLADESH	3,806	488	8,290	6	1
BHUTAN	141	69	58	0	0
BRUNEI	1,943	37	65	0	0
BURMA	89,832	3,531	5,111	20	4

TOTAL CURRENT EMISSIONS BY GAS (cont'd)

REGION	COUNTRY	CO2 (kT C)	CO (kT C)	CH4 (kT)	N2O (kT)	CFCs (kT CFC-11 equiv.)
	HONG KONG	10,942	73	91	3	1
	INDIA	165,125	8,605	42,079	98	12
	INDONESIA	158,212	5,483	8,876	41	17
	KAMPUCHEA	5,108	284	1,493	1	1
	KOREA, REPUBLIC OF	56,858	1,517	1,720	13	4
	MALAYSIA	70,811	2,287	935	15	3
	NEPAL	9,319	709	1,373	3	2
	PAKISTAN	15,613	884	3,714	12	10
	PAPUA NEW GUINEA	43,291	1,464	204	8	0
	PHILIPPINES	38,801	2,101	2,614	11	6
	SINGAPORE	16,026	133	61	2	5
	SRI LANKA	6,839	446	811	3	0
	TAIWAN	28,312	515	617	8	2
	THAILAND	70,495	3,957	9,372	20	5
MIDDLE EAST		183,009	12,307	6,237	80	14
	AFGHANISTAN	1,756	114	409	1	2
	BAHRAIN	3,776	29	75	1	0
	CYPRUS	1,264	40	17	0	0
	IRAN	50,239	1,594	1,877	12	5
	IRAQ	19,605	1,012	670	3	1
	ISRAEL	9,829	216	113	2	0
	JORDAN	2,546	106	55	0	0
	KUWAIT	8,607	136	189	1	0
	LEBANON	2,048	142	56	1	0
	OMAN	2,498	45	94	1	0
	QATAR	4,393	43	112	1	0
	SAUDI ARABIA	53,153	1,042	891	11	1
	SYRIA	6,104	314	260	2	1
	UNITED ARAB EMIRATES	14,855	327	327	3	2
	YEMEN, ARAB REPUBLIC	1,081	128	134	0	1
	YEMEN, PDR	1,254	119	58	0	0
AFRICA		445,210	103,107	33,642	596	60
	ALGERIA	12,807	480	805	4	2
	ANGOLA	14,381	537	334	3	1
	BENIN	2,793	162	95	1	0
	BOTSWANA	1,182	44	117	0	0
	BURKINA FASO	3,240	236	221	1	1
	BURUNDI	-121	83	50	0	0
	CENTRAL AFRICAN REPU	2,904	145	140	1	0
	CAMEROON	22,992	1,039	436	5	0
	CHAD	2,618	112	276	0	0
	CONGO	9,707	392	82	2	0
	EGYPT	22,812	650	1,035	6	6
	ETHIOPIA	5,074	917	1,809	4	4
	GABON	9,178	355	85	2	0
	GAMBIA	639	40	39	0	0
	GHANA	7,443	318	190	1	1
	GUINEA	11,453	445	419	2	1
	GUINEA-BISSAU	5,951	187	91	1	0
	IVORY COAST	21,692	976	288	5	1
	KENYA	5,440	941	853	4	0
	LESOTHO	111	46	61	0	0

TOTAL CURRENT EMISSIONS BY GAS (cont'd)

REGION / COUNTRY	CO2 (kT C)	CO (kT C)	CH4 (kT)	N2O (kT)	CFCs (kT CFC-11 equiv.)
LIBERIA	12,081	525	94	3	0
LIBYA	8,182	258	390	2	0
MADAGASCAR	23,960	1,037	1,695	5	1
MALAWI	5,385	361	110	2	1
MALI	1,328	128	506	1	1
MAURITANIA	1,501	51	201	0	0
MAURITIUS	347	49	10	0	0
MOROCCO	3,441	125	532	1	2
MOZAMBIQUE	7,008	467	229	2	1
NAMIBIA	1,389	27	185	0	0
NIGER	2,785	137	342	1	1
NIGERIA	54,619	3,852	2,213	17	9
REUNION	163	19	7	0	0
RWANDA	720	149	63	1	1
SOUTH AFRICA	67,940	2,149	3,760	22	14
SENEGAL	2,339	129	247	1	1
SIERRA LEONE	1,757	122	146	1	0
SOMALIA	1,587	191	944	1	0
SUDAN	19,951	773	1,426	4	2
SWAZILAND	-481	51	37	0	0
TANZANIA	6,909	791	1,049	3	2
TOGO	981	40	56	0	0
TUNISIA	2,912	129	176	1	1
UGANDA	4,033	377	294	2	1
ZAIRE	33,982	1,655	408	8	3
ZAMBIA	12,051	652	231	3	1
ZIMBABWE	6,041	259	363	2	1
LATIN AMERICA	795,817	121,431	40,722	749	49
ARGENTINA	54,476	2,458	4,662	12	3
BOLIVIA	12,755	514	502	2	1
BRAZIL	270,310	17,881	12,574	133	14
CHILE	-255	497	382	2	1
COLOMBIA	73,105	3,797	1,972	16	3
COSTA RICA	15,863	565	187	3	0
CUBA	8,399	732	543	4	1
DOMINICAN REPUBLIC	2,284	117	217	1	1
ECUADOR	29,166	1,346	629	18	1
EL SALVADOR	1,556	149	94	1	0
GUATEMALA	18,501	853	238	4	2
GUYANA	687	34	100	2	0
HAITI	439	127	165	1	1
HONDURAS	12,908	511	213	3	0
JAMAICA	1,829	104	32	0	0
MEXICO	133,522	4,806	3,625	36	11
NICARAGUA	25,982	868	238	5	0
PANAMA	11,726	401	164	2	0
PARAGUAY	44,034	1,572	567	10	0
PERU	35,979	1,639	845	7	2
TRINIDAD & TOBAGO	5,204	23	106	1	0
URUGUAY	488	130	701	1	0
VENEZUELA	36,860	1,808	1,465	12	5

ENERGY AND INDUSTRY

REGION COUNTRY	Energy 1988 CO2 (kT C)	 CO (kT C)	 CH4 (kT)	 N2O (kT)	Cement 1988 CO2 (kT C)
WORLD TOTAL	*5,426,426*	*211,936*	*79,188*	*1,312*	*149,498*
NORTH AMERICA	1,405,913	69,099	12,899	373	11,367
CANADA	109,586	8,072	1,041	26	1,715
U.S.A.	1,296,328	61,028	11,858	347	9,653
EUROPE	1,217,820	43,357	12,579	265	36,605
ALBANIA	2,570	84	26	1	109
AUSTRIA	13,219	1,096	67	3	629
BELGIUM	30,659	901	122	5	740
BULGARIA	30,110	455	207	8	752
CZECHOSLOVAKIA	62,551	825	692	13	1,382
DENMARK	15,913	526	22	4	271
FINLAND	14,136	833	21	4	204
FRANCE	90,617	5,813	444	19	3,269
GERMANY	270,579	8,401	2,608	62	5,918
GREECE	18,904	509	95	4	1,764
HUNGARY	18,112	525	298	4	527
ICELAND	525	29	0	0	18
IRELAND	6,694	310	31	1	190
ITALY	101,643	3,578	250	18	5,066
LUXEMBOURG	2,425	86	4	0	75
NETHERLANDS	48,202	1,115	362	8	419
NORWAY	9,581	425	117	2	231
POLAND	123,094	2,091	3,841	28	2,035
PORTUGAL	8,508	419	7	2	777
ROMANIA	57,973	622	595	13	1,900
SPAIN	52,788	2,535	357	11	3,269
SWEDEN	15,025	1,717	21	4	299
SWITZERLAND	11,470	761	30	2	641
TURKEY	28,411	1,640	152	8	3,083
UNITED KINGDOM	151,998	7,278	2,023	32	1,835
YUGOSLAVIA	32,113	786	186	8	1,202
JANZ	326,892	12,286	1,848	70	11,481
AUSTRALIA	62,434	3,038	1,321	18	814
FIJI	227	25	2	0	
JAPAN	258,865	8,890	464	51	10,545
NEW ZEALAND	5,367	333	61	1	122
USSR	950,984	15,191	17,887	212	18,873
CENTRALLY PLANNED ASIA	614,571	14,117	18,818	120	29,225
CHINA	571,989	12,895	17,921	109	27,631
KOREA, DPR	35,564	466	761	7	1,357
LAOS	56	76	7	0	
MONGOLIA	2,543	71	35	1	34
VIETNAM	4,419	609	95	3	204
SOUTH & EAST ASIA	334,169	16,448	4,576	102	17,786
BANGLADESH	4,011	456	93	2	42
BHUTAN	9	61	6	0	
BRUNEI	1,422	17	60	0	
BURMA	1,282	411	52	2	47

ENERGY AND INDUSTRY (cont'd)

REGION / COUNTRY	Energy 1988 CO2 (kT C)	Energy 1988 CO (kT C)	Energy 1988 CH4 (kT)	Energy 1988 N2O (kT)	Cement 1988 CO2 (kT C)
HONG KONG	10,635	73	3	3	298
INDIA	133,927	7,045	2,543	50	5,539
INDONESIA	32,889	905	408	6	1,665
KAMPUCHEA	121	110	10	0	
KOREA, REPUBLIC OF	53,156	1,509	471	8	3,942
MALAYSIA	12,686	415	196	3	471
NEPAL	222	381	36	1	29
PAKISTAN	14,891	857	254	5	987
PAPUA NEW GUINEA	622	138	12	1	
PHILIPPINES	9,376	1,048	82	4	580
SINGAPORE	15,856	133	10	2	217
SRI LANKA	1,282	219	17	1	54
TAIWAN	25,962	515	26	5	2,350
THAILAND	15,820	2,155	299	8	1,566
MIDDLE EAST	176,364	5,407	2,026	33	6,508
AFGHANISTAN	1,848	114	19	1	14
BAHRAIN	3,776	29	67	1	
CYPRUS	1,165	40	1	0	117
IRAN	48,652	1,594	424	9	1,702
IRAQ	17,704	1,012	231	3	1,431
ISRAEL	9,476	216	3	2	280
JORDAN	2,346	106	1	0	242
KUWAIT	8,469	136	148	1	138
LEBANON	1,977	142	2	0	123
OMAN	2,498	45	70	0	
QATAR	4,351	43	105	1	41
SAUDI ARABIA	51,844	1,042	620	9	1,295
SYRIA	5,621	314	29	1	571
UNITED ARAB EMIRATES	14,411	327	292	3	444
YEMEN, ARAB REPUBLIC	972	128	13	0	109
YEMEN, PDR	1,254	119	2	0	
AFRICA	160,987	13,757	4,646	65	6,208
ALGERIA	15,542	480	434	3	884
ANGOLA	1,936	108	99	0	48
BENIN	106	119	10	0	41
BOTSWANA	653	34	8	0	
BURKINA FASO	131	169	16	1	
BURUNDI	46	83	8	0	
CENTRAL AFRICAN REPUBLIC	61	74	7	0	
CAMEROON	603	321	53	1	
CHAD	73	71	7	0	
CONGO	241	73	24	0	8
EGYPT	21,836	650	261	4	1,221
ETHIOPIA	736	803	73	3	34
GABON	1,156	82	40	0	20
GAMBIA	51	20	2	0	
GHANA	545	90	1	0	65
GUINEA	277	89	8	0	
GUINEA-BISSAU	41	10	1	0	
IVORY COAST	1,036	289	23	1	95
KENYA	1,636	784	69	3	168
LESOTHO	111	46	4	0	

ENERGY AND INDUSTRY (cont'd)

REGION / COUNTRY	Energy 1988 CO2 (kT C)	Energy 1988 CO (kT C)	Energy 1988 CH4 (kT)	Energy 1988 N2O (kT)	Cement 1988 CO2 (kT C)
LIBERIA	245	104	9	0	14
LIBYA	9,380	258	266	2	370
MADAGASCAR	351	159	14	1	5
MALAWI	166	285	26	1	9
MALI	122	109	10	0	3
MAURITANIA	838	35	0	0	
MAURITIUS	409	49	4	0	
MOROCCO	4,996	125	12	1	518
MOZAMBIQUE	455	319	30	1	61
NAMIBIA	679	11	0	0	
NIGER	211	89	9	0	5
NIGERIA	15,881	2,449	509	9	454
REUNION	210	19	1	0	
RWANDA	110	121	11	0	
SOUTH AFRICA	67,888	2,149	2,223	18	1,128
SENEGAL	822	104	8	0	51
SIERRA LEONE	242	67	6	0	
SOMALIA	271	149	13	1	
SUDAN	1,375	481	41	2	24
SWAZILAND	222	51	5	0	
TANZANIA	516	638	59	2	41
TOGO	79	17	1	0	51
TUNISIA	2,989	129	29	1	678
UGANDA	224	265	24	1	3
ZAIRE	1,058	692	70	3	54
ZAMBIA	781	270	28	1	47
ZIMBABWE	3,648	218	91	1	105
LATIN AMERICA	238,726	22,275	3,909	72	11,443
ARGENTINA	30,982	1,588	890	6	822
BOLIVIA	1,210	157	23	0	52
BRAZIL	53,881	10,338	748	27	3,444
CHILE	6,562	497	45	2	217
COLOMBIA	11,402	2,010	224	4	920
COSTA RICA	573	93	7	0	76
CUBA	8,626	717	45	3	506
DOMINICAN REPUBLIC	1,548	98	7	0	203
ECUADOR	3,501	471	74	1	271
EL SALVADOR	571	119	9	0	81
GUATEMALA	822	316	19	1	205
GUYANA	277	18	1	0	
HAITI	181	119	11	0	27
HONDURAS	440	129	11	0	54
JAMAICA	1,365	89	2	0	53
MEXICO	74,444	2,813	986	16	3,110
NICARAGUA	553	93	7	0	14
PANAMA	2,501	140	6	0	47
PARAGUAY	364	175	11	0	44
PERU	5,246	618	56	1	345
TRINIDAD & TOBAGO	5,157	20	91	1	49
URUGUAY	1,304	130	6	0	59
VENEZUELA	27,217	1,525	630	5	843

HALOCARBONS

REGION / COUNTRY	1985 CFC-11 (kT)	CFC-12 (kT)	CCl4 (kT)	CFC-113 (kT)	CFC-114 (kT)	CFC-115 (kT)	CH3CCl3 (kT)	H-1211 (kT)	H-1301 (kT)	HCFC-22 (kT)
WORLD TOTAL	**291**	**360**	**86**	**152**	**17**	**5**	**810**	**2**	**3**	**97**
NORTH AMERICA	69.6	101.2	24.3	42.3	5.8	2.6	401.4	0.8	0.7	63.7
CANADA	4.2	6.1	1.1	2.5	0.3	0.2	7.1	0.1	0.0	0.3
U.S.A.	65.4	95.1	23.2	39.8	5.4	2.5	394.3	0.8	0.7	63.4
EUROPE	123.9	115.9	30.3	42.2	5.1	1.3	201.6	0.8	0.8	13.4
ALBANIA	0.3	0.7	0.1	0.1	0.0	0.0	0.8	0.0	0.0	0.0
AUSTRIA	2.1	2.4	0.3	1.0	0.1	0.1	2.3	0.0	0.0	0.1
BELGIUM	4.3	4.9	0.4	2.0	0.3	0.1	3.0	0.0	0.0	0.2
BULGARIA	1.0	2.1	0.4	0.3	0.1	0.0	2.5	0.0	0.0	0.1
CZECHOSLOVAKIA	1.4	2.8	0.7	0.8	0.0	0.0	4.4	0.0	0.0	0.2
DENMARK	1.5	1.7	0.2	0.7	0.1	0.0	1.6	0.0	0.0	0.1
FINLAND	0.9	1.0	0.2	0.4	0.1	0.0	1.4	0.0	0.0	0.1
FRANCE	17.6	12.4	3.9	5.4	0.6	0.1	26.5	0.1	0.1	1.9
GERMANY	22.6	20.0	5.1	7.9	0.8	0.2	34.0	0.1	0.1	2.3
GREECE	1.8	1.6	0.5	0.5	0.1	0.0	3.0	0.0	0.0	0.2
HUNGARY	0.6	1.2	0.4	0.4	0.0	0.0	2.2	0.0		0.1
ICELAND	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
IRELAND	0.6	0.6	0.2	0.2	0.0	0.0	1.1	0.0	0.0	0.1
ITALY	18.2	12.9	4.1	5.6	0.6	0.1	27.5	0.1	0.1	2.0
LUXEMBOURG	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
NETHERLANDS	2.3	2.7	1.0	1.1	0.2	0.1	7.0	0.1	0.0	0.5
NORWAY	0.4	0.4	0.2	0.2	0.0	0.0	1.3	0.0	0.0	0.1
POLAND	3.0	6.4	1.3	0.8	0.2	0.0	7.9	0.0	0.0	0.4
PORTUGAL	1.9	1.6	0.5	0.6	0.1	0.0	3.1	0.0	0.0	0.2
ROMANIA	2.5	5.2	1.0	0.7	0.1	0.0	6.4	0.0	0.0	0.3
SPAIN	5.5	6.3	1.8	2.5	0.4	0.2	11.7	0.1	0.1	0.8
SWEDEN	1.4	1.6	0.4	0.6	0.1	0.0	2.4	0.0	0.0	0.1
SWITZERLAND	2.2	2.5	0.3	1.0	0.2	0.1	1.8	0.0	0.0	0.1
TURKEY	9.2	8.2	2.3	2.8	0.3	0.1	15.3	0.0	0.0	1.0
UNITED KINGDOM	18.1	12.8	4.0	5.6	0.6	0.1	27.2	0.1	0.1	2.0
YUGOSLAVIA	4.2	3.7	1.1	1.3	0.2	0.0	7.0	0.0	0.0	0.5
JANZ	22.9	33.8	7.5	47.4	2.3	0.3	48.8	0.1	0.4	12.0
AUSTRALIA	2.7	3.5	0.8	4.3	0.1	0.0	5.4	0.0	0.0	1.3
FIJI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JAPAN	19.6	29.6	6.3	42.8	2.1	0.3	40.9	0.1	0.3	10.1
NEW ZEALAND	0.6	0.6	0.4	0.3	0.0	0.0	2.5	0.0	0.0	0.6
USSR	22.5	47.5	9.4	6.1	1.3	0.3	58.3	0.2	0.2	2.8
CENTRALLY PLANNED ASIA	3.1	7.1	1.3	0.9	0.2	0.1	8.6	0.0	0.0	0.4
CHINA	2.0	5.8	1.0	0.7	0.2	0.1	6.6	0.0	0.0	0.3
KOREA, DPR	0.7	0.7	0.2	0.1	0.0	0.0	1.2	0.0		0.0
LAOS	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0		0.0
MONGOLIA	0.2	0.4	0.1	0.1	0.0	0.0	0.5	0.0	0.0	0.0
VIETNAM	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0		0.0
SOUTH & EAST ASIA	17.6	19.7	5.6	5.5	0.8	0.1	37.4	0.2	0.3	1.7
BANGLADESH			0.8				5.5			0.3
BHUTAN	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
BRUNEI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BURMA	1.2	1.1	0.3	0.2	0.1	0.0	2.1	0.0	0.0	0.1

HALOCARBONS (cont'd)

REGION	COUNTRY	CFC-11 (kT)	CFC-12 (kT)	CCl4 (kT)*	CFC-113 (kT)	CFC-114 (kT)	CFC-115 (kT)	CH3CCl3 (kT)	H-1211 (kT)	H-1301 (kT)	HCFC-22 (kT)
		1985									
	HONG KONG	0.2	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
	INDIA	1.5	4.1	0.8	0.5	0.1		4.8	0.1	0.1	0.2
	INDONESIA	4.9	4.6	1.2	0.9	0.2	0.1	8.2	0.0	0.0	0.4
	KAMPUCHEA	0.2	0.2	0.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0
	KOREA, REPUBLIC OF	1.2	1.1	0.3	0.2			2.0	0.0		0.1
	MALAYSIA	0.3	0.5	0.1	0.8	0.0	0.0	0.9	0.0	0.0	0.0
	NEPAL	0.5	0.5	0.1	0.1	0.0	0.0	0.9	0.0	0.0	0.0
	PAKISTAN	2.9	2.7	0.7	0.5	0.1		4.8	0.0		0.2
	PAPUA NEW GUINEA	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	PHILIPPINES	1.6	1.5	0.4	0.3	0.1		2.7	0.0		0.1
	SINGAPORE	0.7	1.0	0.0	1.5	0.1	0.0	0.1	0.0	0.1	0.0
	SRI LANKA	0.0	0.1	0.1	0.1	0.0	0.0	0.9	0.0	0.0	0.0
	TAIWAN	0.6	0.5	0.1	0.1			1.0	0.0		
	THAILAND	1.5	1.4	0.4	0.3	0.1		2.6	0.0		0.1
MIDDLE EAST		2.8	3.3	0.8	2.7	0.2	0.0	5.5	0.1	0.1	0.3
	AFGHANISTAN	0.5	0.4	0.1	0.1	0.0	0.0	0.8	0.0	0.0	0.0
	BAHRAIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CYPRUS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	IRAN	0.6	1.0	0.3	1.4	0.1	0.0	1.9	0.0	0.0	0.1
	IRAQ	0.4	0.4	0.1	0.1	0.0	0.0	0.7	0.0	0.0	0.0
	ISRAEL	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	JORDAN	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
	KUWAIT	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	LEBANON	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	OMAN	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	QATAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SAUDI ARABIA	0.3	0.3	0.1	0.1	0.0	0.0	0.5	0.0	0.0	0.0
	SYRIA	0.1	0.2	0.1	0.3	0.0	0.0	0.5	0.0	0.1	0.0
	UNITED ARAB EMIRATES	0.2	0.4	0.0	0.5	0.0	0.0	0.1	0.0	0.0	0.0
	YEMEN, ARAB REPUBLIC	0.2	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
	YEMEN, PDR	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
AFRICA		17.1	16.1	4.2	3.1	0.7	0.2	28.3	0.1	0.2	1.4
	ALGERIA	0.5	0.5	0.2	0.1	0.0	0.0	1.1	0.0		0.1
	ANGOLA	0.2	0.2	0.1	0.0	0.0	0.0	0.4	0.0		0.0
	BENIN	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0		0.0
	BOTSWANA	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0		0.0
	BURKINA FASO	0.2	0.2	0.1	0.0	0.0	0.0	0.4	0.0		0.0
	BURUNDI	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0		0.0
	CENTRAL AFRICAN REPU	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0		0.0
	CAMEROON			0.1				0.5			0.0
	CHAD	0.1	0.1	0.0	0.0	0.0	0.0	0.3	0.0		0.0
	CONGO	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0		0.0
	EGYPT	1.7	1.6	0.4	0.3	0.1	0.0	2.4	0.0	0.0	0.1
	ETHIOPIA	1.0	1.0	0.3	0.2	0.0	0.0	2.2	0.0		0.1
	GABON	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0		0.0
	GAMBIA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
	GHANA	0.3	0.3	0.1	0.1	0.0	0.0	0.6	0.0		0.0
	GUINEA	0.2	0.1	0.0	0.0	0.0	0.0	0.3	0.0		0.0
	GUINEA-BISSAU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
	IVORY COAST	0.3	0.2	0.1	0.0	0.0	0.0	0.5	0.0		0.0
	KENYA	0.0	0.0	0.2	0.0	0.0	0.0	1.0	0.0	0.0	0.1

HALOCARBONS (cont'd)

1985

REGION / COUNTRY	CFC-11 (kT)	CFC-12 (kT)	CCl4 (kT)	CFC-113 (kT)	CFC-114 (kT)	CFC-115 (kT)	CH3CCl3 (kT)	H-1211 (kT)	H-1301 (kT)	HCFC-22 (kT)
LESOTHO	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0		0.0
LIBERIA	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0		0.0
LIBYA	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0		0.0
MADAGASCAR	0.3	0.2	0.1	0.0	0.0	0.0	0.5	0.0		0.0
MALAWI	0.2	0.2	0.1	0.0	0.0	0.0	0.4	0.0		0.0
MALI	0.2	0.2	0.1	0.0	0.0	0.0	0.4	0.0		0.0
MAURITANIA	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0		0.0
MAURITIUS	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0		0.0
MOROCCO	0.5	0.5	0.2	0.1	0.0	0.0	1.1	0.0		0.1
MOZAMBIQUE	0.3	0.3	0.1	0.1	0.0	0.0	0.7	0.0		0.0
NAMIBIA	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0		0.0
NIGER	0.2	0.2	0.1	0.0	0.0	0.0	0.3	0.0		0.0
NIGERIA	2.5	2.3	0.8	0.4	0.1	0.0	5.1	0.0		0.3
REUNION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RWANDA	0.1	0.1	0.0	0.0	0.0	0.0	0.3	0.0		0.0
SOUTH AFRICA	4.2	3.9	0.2	0.7	0.2	0.0	1.6	0.0	0.1	0.1
SENEGAL	0.2	0.2	0.1	0.0	0.0	0.0	0.3	0.0		0.0
SIERRA LEONE	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0		0.0
SOMALIA	0.1	0.1	0.0	0.0	0.0	0.0	0.3	0.0		0.0
SUDAN	0.5	0.5	0.2	0.1	0.0	0.0	1.1	0.0		0.1
SWAZILAND	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
TANZANIA	0.5	0.5	0.2	0.1	0.0	0.0	1.1	0.0		0.1
TOGO	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0		0.0
TUNISIA	0.3	0.2	0.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0
UGANDA	0.4	0.3	0.1	0.1	0.0	0.0	0.7	0.0		0.0
ZAIRE	0.9	0.9	0.2	0.2	0.0	0.0	1.5	0.0	0.0	0.1
ZAMBIA	0.2	0.2	0.1	0.0	0.0	0.0	0.3	0.0		0.0
ZIMBABWE	0.2	0.2	0.1	0.0	0.0	0.0	0.4	0.0		0.0
LATIN AMERICA	11.0	15.4	3.0	2.1	0.5	0.1	20.0	0.0	0.1	1.0
ARGENTINA	0.9	0.9	0.2	0.2	0.0	0.0	1.6	0.0	0.0	0.1
BOLIVIA	0.2	0.2	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0
BRAZIL	4.0	3.7	1.0	0.7	0.2	0.1	6.6	0.0	0.0	0.3
CHILE	0.1	0.4	0.1	0.0	0.0	0.0	0.6	0.0	0.0	0.0
COLOMBIA	0.9	0.8	0.2	0.2	0.0	0.0	1.5	0.0	0.0	0.1
COSTA RICA	0.1	0.1	0.0	0.0			0.1	0.0		0.0
CUBA	0.3	0.3	0.1	0.1	0.0	0.0	0.5	0.0	0.0	0.0
DOMINICAN REPUBLIC	0.2	0.2	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0
ECUADOR	0.1	0.3	0.1	0.0	0.0	0.0	0.5			0.0
EL SALVADOR	0.2	0.1	0.0	0.0			0.2	0.0		0.0
GUATEMALA	0.3	0.9	0.1	0.1	0.0	0.0	0.4	0.0	0.0	0.0
GUYANA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HAITI	0.2	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
HONDURAS	0.1	0.1	0.0	0.0			0.2	0.0		0.0
JAMAICA	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
MEXICO	1.5	4.2	0.6	0.3	0.1	0.0	4.1			0.2
NICARAGUA	0.1	0.1	0.0	0.0			0.2	0.0		0.0
PANAMA	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
PARAGUAY	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
PERU	0.6	0.6	0.2	0.1	0.0	0.0	1.0	0.0	0.0	0.1
TRINIDAD & TOBAGO	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
URUGUAY	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
VENEZUELA	0.7	2.0	0.1	0.2	0.0	0.0	0.8	0.0	0.0	

LANDFILLS BIOTA

REGION / COUNTRY	LANDFILLS 1985 CH4 (kT)	BIOTA 1985 CO2 (kT C)	CO (kT C)	CH4 (kT)	N2O (kT)
WORLD TOTAL	**35,726**	**855,938**	**273,639**	**35,819**	**1,669**
NORTH AMERICA	11,059	-139,356	18,400	2,400	108
CANADA	1,093	-79,050			
U.S.A.	9,966	-60,306			
EUROPE	8,361	-62,219	2,300	300	14
ALBANIA	17	-252			
AUSTRIA	27	-2,671			
BELGIUM	236	125			
BULGARIA	101	-891			
CZECHOSLOVAKIA	171	-736			
DENMARK	137	-627			
FINLAND	107	-8,274			
FRANCE	836	-7,741			
GERMANY	1,312	-6,833			
GREECE	148	-381			
HUNGARY	39	-1,367			
ICELAND	5				
IRELAND	50	-2,110			
ITALY	710	-67			
LUXEMBOURG	7				
NETHERLANDS	171	516			
NORWAY	78	-2,476			
POLAND	706	-3,475			
PORTUGAL	66	-1,945			
ROMANIA	188	-2,101			
SPAIN	767	-6,214			
SWEDEN	86	-8,315			
SWITZERLAND	33	-305			
TURKEY	575	-2,079			
UNITED KINGDOM	1,521	419			
YUGOSLAVIA	266	-4,421			
JANZ	1,758	1,073	6,900	900	41
AUSTRALIA	967	-2,576			
FIJI	3	84			
JAPAN	721	4,391			
NEW ZEALAND	68	-826			
USSR	3,085	-140,371	2,300	300	14
CENTRALLY PLANNED ASIA	2,356	-66,506	9,200	1,200	54
CHINA	2,085	-105,571			
KOREA, DPR	127	-58			
LAOS	6	-25			
MONGOLIA	16	-134			
VIETNAM	122	39,282			
SOUTH & EAST ASIA	3,325	439,517	39,132	5,151	224
BANGLADESH	117	-248	31	4	0
BHUTAN	1	131	8	1	0
BRUNEI	1	521	20	3	0
BURMA	87	88,503	3,120	416	17
HONG KONG	85	9			

Note: *Additional biomass burning (agricultural residue, and grassland burning etc.) may produce 230,000 kt CO C and 30,000 kt CH4 (Crutzen and Andreae 1990) and 1,350 kT N2O globally (Cofer et al. 1991). These emissions appear in the regional totals, not the country estimates.*

LANDFILLS **BIOTA** **(cont'd)**

REGION / COUNTRY	LANDFILLS 1985 CH4 (kT)	BIOTA 1985 CO2 (kT C)	CO (kT C)	CH4 (kT)	N2O (kT)
INDIA	1,443	25,659	1,560	208	9
INDONESIA	462	123,659	4,578	610	25
KAMPUCHEA	8	4,987	174	23	1
KOREA, REPUBLIC OF	261	-241	8	1	0
MALAYSIA	58	57,654	1,872	250	10
NEPAL	13	9,067	328	44	2
PAKISTAN	279	-264	27	4	0
PAPUA NEW GUINEA	5	42,669	1,326	177	7
PHILIPPINES	215	28,846	1,053	140	6
SINGAPORE	42	-47			
SRI LANKA	26	5,503	226	30	1
TAIWAN	123				
THAILAND	100	53,109	1,802	240	10
MIDDLE EAST	1,340	138	6,900	900	41
AFGHANISTAN	69	-105			
BAHRAIN	7				
CYPRUS	7	-18			
IRAN	473	-115			
IRAQ	232	470			
ISRAEL	79	72			
JORDAN	35	-42			
KUWAIT	33				
LEBANON	44	-52			
OMAN	2				
QATAR	5				
SAUDI ARABIA	175	14			
SYRIA	107	-87			
UNITED ARAB EMIRATES	22				
YEMEN, ARAB REPUBLIC	32				
YEMEN, PDR	18				
AFRICA	1,758	278,015	89,350	11,680	521
ALGERIA	90	-3,619			
ANGOLA	21	12,397	429	57	2
BENIN	14	2,646	43	6	0
BOTSWANA	2	529	10	1	0
BURKINA FASO	6	3,109	67	9	0
BURUNDI	3	-167			
CENTRAL AFRICAN REPU	11	2,844	71	10	0
CAMEROON	42	22,388	718	96	4
CHAD	13	2,545	41	5	0
CONGO	7	9,458	319	43	2
EGYPT	129	-245			
ETHIOPIA	48	4,304	114	15	1
GABON	4	8,002	273	36	2
GAMBIA	1	588	20	3	0
GHANA	19	6,833	227	30	1
GUINEA	13	11,177	355	47	2
GUINEA-BISSAU	2	5,910	176	23	1
IVORY COAST	42	20,562	686	92	4
KENYA	39	3,636	157	21	1
LESOTHO	3				
LIBERIA	8	11,822	422	56	2
LIBYA	24	-1,568			

LANDFILLS BIOTA (cont'd)

REGION / COUNTRY	Landfills 1985 CH4 (kT)	Biota 1985 CO2 (kT C)	CO (kT C)	CH4 (kT)	N2O (kT)
MADAGASCAR	22	23,604	878	117	5
MALAWI	9	5,210	77	10	0
MALI	13	1,203	18	2	0
MAURITANIA	6	663	16	2	0
MAURITIUS	4	-63			
MOROCCO	96	-2,073			
MOZAMBIQUE	26	6,492	148	20	1
NAMIBIA	6	710	15	2	0
NIGER	10	2,568	48	6	0
NIGERIA	301	38,284	1,403	187	8
REUNION	3	-47			
RWANDA	4	610	29	4	0
SOUTH AFRICA	344	-1,075			
SENEGAL	23	1,466	26	3	0
SIERRA LEONE	10	1,515	55	7	0
SOMALIA	17	1,316	42	6	0
SUDAN	44	18,551	292	39	2
SWAZILAND	2	-703			
TANZANIA	53	6,352	153	20	1
TOGO	7	850	23	3	0
TUNISIA	42	-755			
UGANDA	13	3,806	112	15	1
ZAIRE	109	32,869	963	128	5
ZAMBIA	32	11,223	382	51	2
ZIMBABWE	20	2,287	41	5	0
LATIN AMERICA	2,684	545,648	99,156	12,988	654
ARGENTINA	250	22,672	871	116	5
BOLIVIA	30	11,493	357	48	2
BRAZIL	959	212,986	7,543	1,006	101
CHILE	99	-7,035			
COLOMBIA	201	60,783	1,788	238	10
COSTA RICA	12	15,215	472	63	3
CUBA	71	-733	15	2	0
DOMINICAN REPUBLIC	35	532	19	3	0
ECUADOR	48	25,394	875	117	17
EL SALVADOR	20	904	30	4	0
GUATEMALA	31	17,474	537	72	3
GUYANA	2	410	15	2	1
HAITI	16	231	8	1	0
HONDURAS	17	12,414	382	51	2
JAMAICA	11	410	15	2	0
MEXICO	532	55,968	1,993	266	11
NICARAGUA	18	25,415	775	103	4
PANAMA	11	9,177	261	35	1
PARAGUAY	16	43,626	1,396	186	10
PERU	127	30,388	1,021	136	6
TRINIDAD & TOBAGO	7	-2	3	0	0
URUGUAY	24	-875			
VENEZUELA	148	8,799	283	38	6

AGRICULTURE

REGION / COUNTRY	Livestock 1988 CH4 (kT)	Rice Cultivation 1988 CH4 (kT)	Fertilizers 1985 N2O (kT)
WORLD TOTAL	103,170	98,495	803
NORTH AMERICA	11,224	775	420
CANADA	1,083		11
U.S.A.	10,140	775	409
EUROPE	16,533	253	102
ALBANIA	82	2	0
AUSTRIA	286		1
BELGIUM	274		1
BULGARIA	284	7	1
CZECHOSLOVAKIA	540		2
DENMARK	294		5
FINLAND	129		3
FRANCE	2,415	11	21
GERMANY	2,393		10
GREECE	254	11	3
HUNGARY	557	9	3
ICELAND	17		0
IRELAND	492		3
ITALY	1,069	105	8
LUXEMBOURG	46		0
NETHERLANDS	589		2
NORWAY	117		2
POLAND	1,106		4
PORTUGAL	205		1
ROMANIA	843	32	3
SPAIN	842	38	6
SWEDEN	174		2
SWITZERLAND	197		0
TURKEY	1,268	34	6
UNITED KINGDOM	1,391		12
YUGOSLAVIA	668	5	2
JANZ	4,974	1,445	8
AUSTRALIA	2,676	77	2
FIJI	9	4	0
JAPAN	989	1,365	7
NEW ZEALAND	1,300		0
USSR	11,724	354	34
CENTRALLY PLANNED ASIA	8,174	30,107	126
CHINA	7,369	25,021	118
KOREA, DPR	74	406	5
LAOS	85	233	0
MONGOLIA	324		0
VIETNAM	322	4,448	2
SOUTH & EAST ASIA	17,737	59,695	74
BANGLADESH	1,089	6,988	3
BHUTAN	19	32	0
BRUNEI	1	1	
BURMA	538	4,017	1

AGRICULTURE (cont'd)

REGION / COUNTRY	Livestock 1988 CH4 (kT)	Rice Cultivation 1988 CH4 (kT)	Fertilizers 1985 N2O (kT)
HONG KONG	4		1
INDIA	11,854	26,030	39
INDONESIA	679	6,717	10
KAMPUCHEA	113	1,340	0
KOREA, REPUBLIC OF	119	868	5
MALAYSIA	59	372	2
NEPAL	498	783	0
PAKISTAN	1,756	1,421	7
PAPUA NEW GUINEA	10		0
PHILIPPINES	280	1,896	1
SINGAPORE	9		0
SRI LANKA	124	614	1
TAIWAN	43	424	2
THAILAND	540	8,192	2
MIDDLE EAST	1,580	392	7
AFGHANISTAN	209	113	0
BAHRAIN	1		0
CYPRUS	10		0
IRAN	733	246	3
IRAQ	174	33	1
ISRAEL	31		0
JORDAN	19		0
KUWAIT	7		0
LEBANON	10		0
OMAN	21		0
QATAR	2		0
SAUDI ARABIA	97		1
SYRIA	125		1
UNITED ARAB EMIRATES	13		0
YEMEN, ARAB REPUBLIC	90		0
YEMEN, PDR	38		0
AFRICA	12,625	2,932	10
ALGERIA	281		0
ANGOLA	145	13	0
BENIN	61	5	0
BOTSWANA	105		0
BURKINA FASO	175	15	0
BURUNDI	31	9	0
CENTRAL AFRICAN REPU	109	4	0
CAMEROON	240	5	0
CHAD	233	18	0
CONGO	6	2	0
EGYPT	338	306	2
ETHIOPIA	1,673		0
GABON	4		0
GAMBIA	20	13	0
GHANA	97	43	0
GUINEA	84	267	0
GUINEA-BISSAU	18	46	0
IVORY COAST	73	59	0
KENYA	712	12	0
LESOTHO	54		0

AGRICULTURE (cont'd)

REGION / COUNTRY	Livestock 1988 CH4 (kT)	Rice Cultivation 1988 CH4 (kT)	Fertilizers 1985 N2O (kT)
LIBERIA	8	12	0
LIBYA	100		0
MADAGASCAR	446	1,096	0
MALAWI	48	17	0
MALI	351	130	0
MAURITANIA	185	7	0
MAURITIUS	3		0
MOROCCO	415	8	0
MOZAMBIQUE	71	82	0
NAMIBIA	177		0
NIGER	306	11	0
NIGERIA	944	273	1
REUNION	2		0
RWANDA	43	2	0
SOUTH AFRICA	1,192	1	4
SENEGAL	168	44	0
SIERRA LEONE	19	103	0
SOMALIA	905	3	0
SUDAN	1,301	1	0
SWAZILAND	30		0
TANZANIA	651	267	0
TOGO	32	13	0
TUNISIA	105		0
UGANDA	225	16	0
ZAIRE	76	24	0
ZAMBIA	116	4	0
ZIMBABWE	246		0
LATIN AMERICA	18,600	2,541	22
ARGENTINA	3,326	80	1
BOLIVIA	342	60	0
BRAZIL	8,866	995	5
CHILE	205	34	0
COLOMBIA	1,102	207	2
COSTA RICA	77	28	0
CUBA	246	180	1
DOMINICAN REPUBLIC	105	68	0
ECUADOR	210	180	0
EL SALVADOR	52	9	0
GUATEMALA	93	23	0
GUYANA	13	82	0
HAITI	94	44	0
HONDURAS	125	9	0
JAMAICA	17		0
MEXICO	1,787	54	9
NICARAGUA	83	26	0
PANAMA	65	46	0
PARAGUAY	333	21	0
PERU	302	224	0
TRINIDAD & TOBAGO	5	2	0
URUGUAY	586	85	0
VENEZUELA	565	85	1

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The Stockholm Environment Institute (SEI) was established by the Swedish Parliament in 1989 as an independent Foundation for the purpose of carrying out global environmental research. To achieve its objective, the Institute receives an annual core grant from the Swedish Government. Additional funding, usually linked to specific projects, is received from both national and international as well as Swedish agencies and institutions. The Institute is governed by an international Board (see inside cover overleaf) whose members are drawn from developing and industrialized countries worldwide and acting in their personal capacitites as distinguished persons of considerable experience in dealing with the issues related to environment and development globally.

Central to the Institute's work are the insights on these issues developed by the Stockholm Conference of 1972 and subsequently elaborated by the work of the Brandt and Palme Commissions and more recently, very powerfully highlighted by the Report of the World Commission for Environment and Development (1987).

Thus, it is now very clear worldwide that pollution and degradation of air, water and land are already damaging and even limiting the planetary resource-base needed for current human survival and future socio-economic development. These growing threats to human health and well-being underline the urgent need to manage the environment with the least possible disturbance and degradation. Such "sustainable" management must be at the core of economic development worldwide.

SEI uses scientific and technical analysis as a point of departure for the specification of "minimal harm" technologies and the development of policies which can contribute to strategies for socially responsible environmental management and economic development. A multidisciplinary rolling programme of research actitivities has been designed around the following main themes, which are being executed via internationally collaborative activities with similar institutions and agencies worldwide:

(1) Environmental Resources, including energy efficiency and global trends, energy, environment and development, and world water resources;

(2) Environmental Technology, including clean production and low waste, energy technology, environmental technology transfer, and agricultural niotechnology;

(3) Environmental Impacts, including environmentally sound management of low-grade fuels, climate change and sustainable development, and coordinated abatement strategies for acid depositions;

(4) Environmental Policy and Management, including environmental problems and urban households, and sustainable environments and common property management; and

(5) POLESTAR, a comprehensive modelling and scenario-based activity, investigating the dynamics of a world with 10 billion people by the middle of the next century.

There is as far as possible an interactive systems approach to these themes and their linked supporting measures.

Apart from its working linkages with the relevant specialized agencies of the UN system, a particular feature of the SEI's shorter term work programme is the role it has played in supporting the work of the Secretariat of the UN Conference on Environment and Development (UNCED) and the action plan Agenda 21 for the next century. This has especially appropriate since the UN General Assembly's resolution establishing UNCED lays down a line of approach closely similar to that adopted for the SEI programme by the Institute's Board in September 1989.

This work programme is carried out by a worldwide network of about 70 full- and part-time and affiliated staff and consultants, who are linked with the SEI Head Office in Stockholm or to the SEI Offices in Boston (USA) and York (UK). An additional centre is being developed in Tallinn, Estonia.

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